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(54) **Piezoelectric resonator, method for adjusting frequency of the piezoelectric resonator and communication apparatus**

(57) A base member 12 of a piezoelectric resonator 10 includes a lamination of twenty piezoelectric layers 12a. These piezoelectric layers 12a are alternately polarized in opposite directions along the longitudinal direction of the base member 12. Inner electrodes 14 are provided between the piezoelectric layers 12a. On one side surface of the base member 12, each of external electrodes 20 and 22 is provided so as to be connected one of two groups of inner electrodes 14 alternating with each other. Cut portions 24 for adjusting a frequency of the piezoelectric resonator 10 to a higher frequency are respectively formed in edge portions of the base member 12 at the opposite ends in the longitudinal direction of the side surface opposite from the one side surface of the base member 12.

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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a piezoelectric resonator, a method for adjusting a frequency of the piezoelectric resonator and a communication apparatus including the piezoelectric resonator. In particular, mechanical vibration of a piezoelectric member is utilized in the piezoelectric resonator. The piezoelectric resonator is used in an electronic component such as a vibrator, a discriminator or a filter.

2. Description of the Related Art

[0002] For example, in a conventional piezoelectric resonator, external electrodes are respectively provided on two major surfaces of a piezoelectric substrate in the form of a plate rectangular or square as viewed in plan, the piezoelectric substrate is polarized in the direction of its thickness, and an electric field is applied along the thickness direction of the piezoelectric material substrate by inputting a signal between the electrodes to cause the piezoelectric substrate vibrates in the direction parallel to the major surface of the piezoelectric substrate.

[0003] This piezoelectric resonator is of an unstiffened type in which the direction of an electric field and the direction of polarization differ from the direction of vibration. This unstiffened type of piezoelectric resonator has an electromechanical coefficient smaller than that of a piezoelectric resonator of a stiffened type in which the direction of an electric field and the direction of polarization coincide with the direction of vibration. The unstiffened type piezoelectric resonator therefore has a comparatively small difference ΔF between a resonant frequency and an antiresonant frequency. This leads to the disadvantage of restricting a bandwidth when the piezoelectric resonator is used as a filter. This means that the bandwidth is small if the piezoelectric resonator is used as a filter. Therefore, the degree of freedom in characteristic design of the piezoelectric resonator or an electronic component such as a filter or vibrator using the piezoelectric resonator is low.

[0004] The above-described piezoelectric resonator using a piezoelectric substrate in the form of a plate rectangular or square as viewed in plan uses first-order resonance of longitudinal vibration. In the above-described piezoelectric resonator, however, strong spurious resonances in high-order modes of odd-number multiples, such as third-order and fifth-order modes, occur due to its structure.

[0005] In addition, while first-order resonance of vibration in the spreading direction is used in the above-described piezoelectric resonator using a piezoelectric substrate in the form of a plate rectangular or square as viewed in plan, the possibility of occurrence of strong spurious resonance such as a triple wave in the spreading direction or one in a thickness mode, due to the structure, is high.

[0006] The applicant of the present invention has therefore proposed a piezoelectric resonator of a laminated structure in which spurious resonances are reduced and in which the difference ΔF between a resonant frequency and an antiresonant frequency is large. Fig. 24 illustrates an example of such a piezoelectric resonator of a laminated structure. A piezoelectric resonator 1 shown in Fig. 24 has a laminated structure such that a plurality of piezoelectric layers 3 and a plurality of inner electrodes 4 constituting a base member 2 having a longitudinal direction are alternately laminated and the plurality of piezoelectric layers 3 are polarized along the longitudinal direction of the base member 2. The piezoelectric resonator 1 of this laminated structure is of a stiffened type in which the direction of polarization, the directions of electric fields and the direction of vibration coincide with each other. Therefore, the piezoelectric resonator 1 has a larger electromechanical coefficient and a larger difference ΔF between a resonant frequency and an antiresonant frequency in comparison with unstiffened type piezoelectric resonators in which the direction of vibration differs from the direction of polarization and the direction of an electric field. Further, in the piezoelectric resonator 1 of the laminated structure, vibration in a mode such as a width mode or thickness mode different from the fundamental vibration cannot occur easily because of the effect of the stiffened type. In the piezoelectric resonator 1 of the laminated structure, end portions of inner electrodes 4 are exposed at each of the side surfaces of the base member 2. Therefore, the end portions of one of the two groups of inner electrodes 4 alternating with each other in one side surface of the base member 2 are covered with insulating film 5a at one end of the base member 2 in the with direction, and an external electrode 6a is thereafter provided so as to be connected to the other alternate inner electrodes 4. Further, the end portions of the other alternate inner electrodes 4 in the one side surface of the base member 2 are covered with insulating film 5b at the other end of the base member 2 in the with direction, and an external electrode 6b is thereafter provided so as to be connected to the alternate inner electrodes 4 on which insulating film 5a is provided.

[0007] However, if the piezoelectric resonator 1 of the laminated structure shown in Fig. 24 is mass-produced, there is a possibility of failure to obtain a desired resonant frequency or antiresonant frequency due to working non-uniformity or the like. A method proposed by the applicant and disclosed in Japanese Patent Laid-open Publication No. 197824/1997 can be used as a frequency adjustment method for reducing an obtained frequency to a desired frequency in a situation where the obtained frequency is higher than the desired resonant or antiresonant frequency. However, no method

has been proposed as a frequency adjustment method for increasing an obtained frequency to a desired frequency in a situation where the obtained frequency is lower than the desired resonant or antiresonant frequency. With respect to a piezoelectric resonator in which longitudinal vibration is excited, a method of increasing the length of the base member by cutting surfaces at the ends in the longitudinal direction may be used since a frequency is determined by the length of the base member. In such a case, however, resulting elements vary in length when adjustment is made to the same frequency, and, if automatization is to be promoted, there is a need to adapt the process in a complicated manner for the desired effect, i.e., a need for jigs according to the length of the piezoelectric resonator, and so on. Automatization under such a condition is difficult, and a variation in characteristics other than the resonant and antiresonant frequencies also results. In practice, therefore, it is difficult to use such a method.

SUMMARY OF THE INVENTION

[0008] It is therefore a main object of the present invention to provide a piezoelectric resonator in which spurious resonance is limited, which has a large difference ΔF between a resonant frequency and an antiresonant frequency, and which has a frequency adjusted to a higher frequency.

[0009] It is another object of the present invention to provide a method for adjusting a frequency of a piezoelectric resonator which makes it possible to easily adjust a frequency of a piezoelectric resonator having reduced spurious resonance and having a large difference ΔF between a resonant frequency and an antiresonant frequency without changing the length of the base member.

[0010] It is yet another object of the present invention to provide a communication apparatus using a piezoelectric resonator in which spurious resonance is limited, which has a large difference ΔF between a resonant frequency and an antiresonant frequency, and which has a frequency adjusted to a higher frequency.

[0011] The present invention provides a piezoelectric resonator, comprising: a base member having a longitudinal direction and vibrated in the longitudinal vibration; a plurality of inner electrodes perpendicular to the longitudinal direction of said base member and arranged along the longitudinal direction of said base member while being spaced apart from each other; a pair of external electrodes provided on a surface of said base member and connected to said electrodes; said base member including a plurality of piezoelectric material layers laminated to each other; said inner electrodes being provided on surfaces of said piezoelectric material layers perpendicular to the longitudinal direction of said base member; said piezoelectric material layers being polarized along the longitudinal direction of said base member; and said base member having at least one cut portion at its edge portions.

[0012] In the above described piezoelectric resonator, said cut portion may be located at corner portions of said base member.

[0013] The present invention also provides a method for adjusting a frequency of a piezoelectric resonator comprising: a base member having a longitudinal direction and vibrated in the longitudinal vibration; a plurality of inner electrodes perpendicular to the longitudinal direction of said base member and arranged along the longtudinal direction of said base member while being spaced apart from each other; and a pair of external electrodes provided on a surface of said base member and connected to said electrodes, said base member including a plurality of piezoelectric material layers laminated to each other, said inner electrodes being provided on surfaces of said piezoelectric material layers perpendicular to the longitudinal direction of said base member, and said piezoelectric material layers being polarized along the longitudinal direction of said base member; comprising the step of: removing at least a portion at edge portions of said base member.

[0014] In the above described method, said portion removed in the removing step may be located at corner portions of said base member.

[0015] The present invention further provides a communication apparatus including a detector, wherein; said detector comprises the above described piezoelectric resonator.

[0016] The present invention further provides a communication apparatus including a band-pass filter, wherein; said band-pass filter comprises a ladder-filter including the above described piezoelectric resonator.

[0017] The piezoelectric resonator in accordance with the present invention is of a stiffened type in which the direction of polarization of a piezoelectric layer the direction of an electric field coincide with the direction of vibration. Therefore, it has a larger electromechanical coefficient and a larger difference ΔF between a resonant frequency and an antiresonant frequency in comparison with a piezoelectric resonator of an unstiffened type in which the direction of vibration differs from the direction of polarization and the direction of an electric field. Because of use of the effect of the stiffened type, vibration cannot occur easily in a mode such as a width mode or a thickness mode different from fundamental vibration in longitudinal vibration.

[0018] And, according to the present invention, a frequency of a piezoelectric resonator in which spurious resonance is limited and which has a large difference ΔF between a resonant frequency and an antiresonant frequency can be adjusted to a higher frequency. Therefore, the piezoelectric resonator can be manufactured at an improved yield.

[0019] Further, according to the present invention, the frequency can be adjusted to a higher frequency without changing the length of the piezoelectric resonator and without changing the waveform.

[0020] In a case where an electronic component is manufactured by using the piezoelectric resonator of the present invention, it can be designed as a chip type electronic component, which can be easily mounted on a circuit board or the like.

[0021] Further, according to the present invention, a communication apparatus using the piezoelectric resonator in which spurious resonance is limited, a difference ΔF between a resonant frequency and an antiresonant frequency is large, and a frequency can be adjusted to a higher frequency can be obtained.

[0022] Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023]

Fig. 1 is a diagram showing one preferred embodiment of a piezoelectric resonator in accordance with the present invention in such a position that its external electrodes face upward.

Fig. 2 is a diagram showing the piezoelectric resonator shown in Fig. 1 in such a position that the external electrode face downward.

Fig. 3 is a graph showing a frequency characteristic of the piezoelectric resonator shown in Figs. 1 and 2 before cut portions are formed (before working) and a frequency characteristic of the piezoelectric resonator after cut portions have been formed (after working).

Fig. 4 is a diagram showing a modification of the piezoelectric resonator shown in Figs. 1 and 2.

Fig. 5 is a diagram showing another modification of the piezoelectric resonator shown in Figs. 1 and 2.

Fig. 6 a diagram showing a modification of the piezoelectric resonator shown in Fig. 4.

Fig. 7 is a diagram showing another preferred embodiment of the piezoelectric resonator in accordance with the present invention.

Fig. 8 is a graph showing a frequency characteristic of the piezoelectric resonator shown in Fig. 7 before cut portions are formed (before working) and a frequency characteristic of the piezoelectric resonator after cut portions have been formed (after working).

Fig. 9 is diagram showing a modification of the piezoelectric resonator shown in Fig. 7.

Fig. 10 is diagram showing another modification of the piezoelectric resonator shown in Fig. 7.

Fig. 11 is diagram showing a modification of the piezoelectric resonator shown in Fig. 9.

Fig. 12 is a diagram showing still another preferred embodiment of the piezoelectric resonator in accordance with the present invention.

Fig. 13 is a diagram showing a cut portion in the resonator shown in Fig. 12.

Fig. 14 is a graph showing a frequency characteristic of the piezoelectric resonator shown in Fig. 12 before cut portions are formed (before working) and a frequency characteristic of the piezoelectric resonator after cut portions have been formed (after working).

Fig. 15 is graph showing the relationship between the depth d of the cut portions and the resonant frequency Fr in the piezoelectric resonator shown in Fig. 12.

Fig. 16 is a diagram showing a modification of the piezoelectric resonator shown in Fig. 12.

Fig. 17 is diagram showing another modification of the piezoelectric resonator shown in Fig. 12.

Fig. 18 is diagram showing a modification of the piezoelectric resonator shown in Fig. 16.

Fig. 19 is a graph showing the relationship between the resonant frequency and the time for barreling for forming a cut portion in the piezoelectric resonator shown in Fig. 18.

Fig. 20 is a diagram showing a preferred embodiment of an electronic component in which the piezoelectric resonator of the present invention is used.

Fig. 21 is a side view of the amount structure for the piezoelectric resonator shown in Fig. 20.

Fig. 22 is a plan view showing a modification of the electrodes used in the piezoelectric resonator.

Fig. 23 is a block diagram showing an embodiment of a double-super-heterodyne receiver according to the present invention.

Fig. 24 is a diagram showing an example of a piezoelectric resonator of a laminated structure constituting the background of the present invention.

PREFERRED EMBODIMENTS OF THE PRESENT INVENTION

[0024] Referring to Figs. 1 and 2, the piezoelectric resonator 10 includes a base member 12 in the form of, for example, a 4.8 × 1 × 1 mm rectangular block. The base member 12 includes, for example, a lamination of twenty piezoelectric material layers 12a of a piezoelectric ceramic. These piezoelectric material layers 12a are formed so as to be uniform in size. These piezoelectric material layers 12a are polarized along the longitudinal direction of the base member 12 so that the directions of polarization of each adjacent pair of the piezoelectric material layers 12a are opposite from each other, as indicated by the arrows in Fig. 1. However, the piezoelectric material layers 12a at the opposite ends are not polarized. Alternatively, the piezoelectric material layers 12a at the opposite ends may also be polarized.

[0025] Inner electrodes 14 are provided between the twenty piezoelectric layers 12a of the base member 12. Thus, these inner electrodes 14 are disposed so as to be perpendicular to the longitudinal direction of the base member 12 while being spaced apart from each

other in the longitudinal direction of the base member 12. Also, these inner electrodes 14 are provided over the entire areas of the major surfaces of the piezoelectric layers 12a. Thus, these inner electrodes 14 are provided so as to be exposed at the four side surfaces of the base member 12.

[0026] One of the two groups of inner electrodes 14 alternating with each other in one side surface of the base member 12 are covered with insulating film 16 at one end of the base member 2 in the with direction, and the other alternate inner electrodes 14 are covered with insulating film 18 at the other end of the base member 12 in the width direction.

[0027] At the one side surface of the base member 12, an external electrode 20 is provided over the insulating film 16 provided on the alternate inner electrodes 14 and so on so as to be connected to the other alternate inner electrodes 14. Further, at the one side surface of the base member 12, an external electrode 22 is provided over the insulating film 18 provided on the other alternate electrodes 14 so as to be connected to the alternate inner electrodes 14.

[0028] Further, cut portions 24 each having a slanted flat surface are respectively formed in edge portions of the base member 12 at the opposite ends in the longitudinal direction of the side surface opposite from the one side surface of the base member 12. These cut portions 24 are formed by grinding, cutting or the like for the purpose of adjusting a resonant frequency or an antiresonant frequency of the piezoelectric resonator 10 to a higher frequency.

[0029] In this piezoelectric resonator 10, the external electrodes 20 and 22 are used as input and output electrodes. An electric field is applied between each adjacent pair of inner electrodes 14 by supplying a signal to the external electrodes 20 and 22. The piezoelectric layers 12a, excepting those at the opposite ends of the base member 12, are thereby made piezoelectrically active. Since in this arrangement electric fields in opposite directions are applied to the piezoelectric layers 12a polarized in the opposite directions, the piezoelectric layers 12a act so as to contract and expand as a whole along one direction. That is, an alternating current electric field in the longitudinal direction of the base member 12 is applied to each piezoelectric layer 12a by the inner electrodes 14 connected to the external electrodes 20 and 22 to cause a contracting and expanding drive force in the piezoelectric layer 12a such that fundamental vibration in longitudinal vibration is excited through the piezoelectric resonator 10 with a node corresponding to the center of the base member 12 in the longitudinal direction.

[0030] In this piezoelectric resonator 10, the direction of polarization of the piezoelectric layers 12a, the directions of electric fields according to an input signal and the direction of vibration of the piezoelectric layers 12a coincide with each other. That is, this piezoelectric resonator 10 is a stiffened type resonator. This piezoelectric resonator 10 has an electromechanical coefficient larger than that of unstiffened type piezoelectric resonators in which the direction of polarization and the direction of an electric field differ from the direction of vibration. Therefore, this piezoelectric resonator 10 has a larger difference ΔF between a resonant frequency and an antiresonant frequency in comparison with the conventional unstiffened type piezoelectric resonator. As a result, this piezoelectric resonator 10 can have a characteristic of a larger bandwidth in comparison with the conventional unstiffened type piezoelectric resonator.

[0031] Further, in this piezoelectric resonator 10, the capacitance of the resonator can be adjusted, for example, by adjusting the opposed area of the inner electrodes 14, the number of piezoelectric layers 12a and the number of inner electrodes 14, or the size of the piezoelectric layers 12a in the longitudinal direction of the base member 12. That is, the capacitance of the resonator can be increased by increasing the opposed area of the inner electrodes 14, by increasing the numbers of the piezoelectric layers 12a and the inner electrodes 14, or by reducing the size of the piezoelectric layers 12a in the longitudinal direction of the base member 22. Conversely, the capacitance of the resonator can be reduced by reducing the opposed area of the inner electrodes 14, by reducing the numbers of the piezoelectric layers 12a and the inner electrodes 14, or by increasing the size of the piezoelectric layers 12a in the longitudinal direction of the base member 12. Thus, the capacitance can be adjusted by adjusting the opposed area of the inner electrodes 14, the numbers of the piezoelectric layers 12a and the inner electrodes 14, or the size of the piezoelectric layers 12a in the longitudinal direction of the base member 12, so that the degree of freedom in capacitance design is high. Therefore, impedance matching with an external circuit can easily be achieved when the piezoelectric resonator 10 is mounted on a circuit board or the like.

[0032] In contrast with the piezoelectric resonator 1 shown in Fig. 24, the piezoelectric resonator 10 shown in Figs. 1 and 2 has cut portions 24 formed in edge portions of the base member 12 at the opposite ends in the longitudinal direction, whereby its frequency is adjusted to a higher frequency. Fig. 3 shows a frequency characteristic of the piezoelectric resonator 10 shown in Figs. 1 and 2 before cut portions 24 are formed (before working) and a frequency characteristic of the piezoelectric resonator 10 after cut portions 24 have been formed (after working). In the piezoelectric resonator 10 shown in Figs. 1 and 2, as is apparent from these characteristics, the frequency can be adjusted in the increasing direction without a change in waveform by forming cut portions 24 in the edge portions of the base member 12 at the opposite ends in the longitudinal direction. Thus, frequency adjustment to a higher frequency can be performed without changing the length. Therefore, a plurality of piezoelectric resonators 10 shown in Figs. 1 and 2

substantially equal to each other in element length can be handled. Thus, the piezoelectric resonator 10 can be adapted to an automated process and is stable in characteristics while the resonant and antiresonant frequencies are changed.

[0033] Fig. 4 is a diagram showing a modification of the piezoelectric resonator shown in Figs. 1 and 2. In comparison with the piezoelectric resonator shown in Figs. 1 and 2, the piezoelectric resonator shown in Fig. 4 is characterized in that cut portions 24 each having a slanted flat surface are formed in edge portions of the base member 12 at the opposite ends in the longitudinal direction of each of two side surfaces of the base member 12 opposite from each other.

[0034] Fig. 5 is a diagram showing another modification of the piezoelectric resonator shown in Figs. 1 and 2. In comparison with the piezoelectric resonator shown in Figs. 1 and 2, the piezoelectric resonator shown in Fig. 5 is characterized in that the surface of each cut portion 24 is curved.

[0035] Fig. 6 is a diagram showing a modification of the piezoelectric resonator shown in Fig. 4. In comparison with the piezoelectric resonator shown in Fig. 4, the piezoelectric resonator shown in Fig. 6 is characterized in that the surface of each cut portion 24 is curved.

[0036] The piezoelectric resonators shown in Figs. 4, 5, and 6 are as advantageous as the piezoelectric resonator shown in Figs. 1 and 2 by the effect of cut portions 24 formed in edge portions of the base member 12 at the opposite ends in the longitudinal direction in the same manner as those in the piezoelectric resonator shown in Figs. 1 and 2.

[0037] Fig. 7 is a diagram showing another preferred embodiment of the piezoelectric resonator in accordance with the present invention. In comparison with the piezoelectric resonator shown in Figs. 1 and 2, the piezoelectric resonator shown in Fig. 7 is characterized in that, in particular, cut portions 24 each having a slanted flat surface are respectively formed in edge portions of the base member 12 at the opposite ends in the width direction of the side surface opposite from the one side surface on which external electrodes 20 and 22 are formed. In contrast with the piezoelectric resonator shown in Fig. 24, the piezoelectric resonator shown in Fig. 7 has cut portions 24 formed in edge portions of the base member 12 at the opposite ends in the width direction to adjust its frequency to a higher frequency. Fig. 8 shows a frequency characteristic of the piezoelectric resonator 10 shown in Fig. 7 before cut portions 24 are formed (before working) and a frequency characteristic of the piezoelectric resonator 10 after cut portions 24 have been formed (after working).

[0038] The piezoelectric resonator arranged as shown in Fig. 7 is also the same stiffed type piezoelectric resonator as the piezoelectric resonator shown in Figs. 1 and 2, has a larger electromechanical coupling coefficient, a larger ΔF, and a characteristic of a wider band in comparison with unstiffened type piezoelectric resonators, and can be designed so as to avoid the problem in the case of promoting automatization of equipment for handling the piezoelectric resonator. Further, it can be easily impedance-matched with an external circuit when mounted on a circuit board or the like.

[0039] Fig. 9 is a diagram showing a modification of the piezoelectric resonator shown in Fig. 7. In comparison with the piezoelectric resonator shown in Fig. 7, the piezoelectric resonator shown in Fig. 9 is characterized in that cut portions 24 each having a slanted flat surface are formed in edge portions of the base member 12 at the opposite ends in the width direction of each of two side surfaces of the base member 12 opposite from each other.

[0040] Fig. 10 is a diagram showing another modification of the piezoelectric resonator shown in Fig. 7. In comparison with the piezoelectric resonator shown in Fig. 7, the piezoelectric resonator shown in Fig. 10 is characterized in that the surface of each cut portion 24 is curved.

[0041] Fig. 11 is a diagram showing a modification of the piezoelectric resonator shown in Fig. 9. In comparison with the piezoelectric resonator shown in Fig. 9, the piezoelectric resonator shown in Fig. 11 is characterized in that the surface of each cut portion 24 is curved.

[0042] The piezoelectric resonators shown in Figs. 9, 10, and 11 are as advantageous as the piezoelectric resonator shown in Fig. 7 by the effect of cut portions 24 formed in edge portions of the base member 12 at the opposite ends in the width direction in the same manner as those in the piezoelectric resonator shown in Fig. 7.

[0043] Fig. 12 is a diagram showing still another preferred embodiment of the piezoelectric resonator in accordance with the present invention, and Fig. 13 is a diagram showing a cut portion in the piezoelectric resonator shown in Fig. 12. In comparison with the piezoelectric resonator shown in Figs. 1 and 2, piezoelectric resonator shown in Fig. 12 is characterized in that cut portions 24 each having a slanted flat surface are respectively formed in corner portions of the base member 12 corresponding to the four corners of the surface opposite from the one surface on which external electrodes 20 and 22 are formed. In contrast with the piezoelectric resonator 1 shown in Fig. 24, the piezoelectric resonator 10 shown in Fig. 12 has cut portions 24 formed in four corner portions of the base member 12 to adjust its frequency to a higher frequency. Fig. 14 shows a frequency characteristic of the piezoelectric resonator 10 shown in Fig. 12 before cut portions 24 are formed (before working) and a frequency characteristic of the piezoelectric resonator 10 after cut portions 24 have been formed (after working).

[0044] The piezoelectric resonator shown in Fig. 12 is also the same stiffed type piezoelectric resonator as the piezoelectric resonator shown in Figs. 1 and 2, has a larger electromechanical coupling coefficient, a larger ΔF, and a characteristic of a wider band in comparison with unstiffened type piezoelectric resonators, and can

be designed so as to avoid the problem in the case of promoting automization of equipment for handling the piezoelectric resonator. Further, it can be easily impedance-matched with an external circuit when mounted on a circuit board or the like.

[0045] Fig. 15 shows the relationship between a depth d of cut portions 24 and a resonant frequency Fr in the piezoelectric resonator 10 shown in Fig. 10. In the piezoelectric resonator 10 shown in Fig. 12, as is apparent from the relationship shown in Fig. 15, the resonant frequency Fr is proportional to the depth d of cut portions 24 when the depth d of cut portions 24 is small, that is, in an initial stage of forming cut portions 24. At this stage, therefore, the resonant frequency Fr can be easily adjusted. Other frequencies of the piezoelectric resonator 10 shown in Fig. 12, including an antiresonant frequency Fa, are also changed according to the depth d of cut portions 24, as is the resonant frequency Fr.

[0046] Frequencies of each of the piezoelectric resonators shown in Figs. 1 to 11, including the resonant and antiresonant frequencies, are also changed according to the depth of cut portions 24, as are the frequencies of the piezoelectric resonator shown in Fig. 12.

[0047] Fig. 16 is a diagram showing a modification of the piezoelectric resonator shown in Fig. 12. In comparison with the piezoelectric resonator shown in Fig. 12, the piezoelectric resonator shown in Fig. 16 is characterized in that cut portions 24 each having a slanted flat surface are formed in all corner portions, i.e., eight corner portions of the base member 12.

[0048] Fig. 17 is a diagram showing another modification of the piezoelectric resonator shown in Fig. 12. In comparison with the piezoelectric resonator shown in Fig. 12, the piezoelectric resonator shown in Fig. 17 is characterized in that the surface of each cut portion 24 is curved.

[0049] Fig. 18 is a diagram showing a modification of the piezoelectric resonator shown in Fig. 16. In comparison with the piezoelectric resonator shown in Fig. 16, the piezoelectric resonator shown in Fig. 18 is characterized in that cut portions 24 each having a curved flat surface are formed in all corner portions, i.e., eight corner portions of the base member 12.

[0050] The piezoelectric resonators shown in Figs. 16, 17, and 18 are as advantageous as the piezoelectric resonator shown in Fig. 12 by the effect of cut portions 24 formed in corner portions of the base member 12 in the same manner as those in the piezoelectric resonator shown in Fig. 12.

[0051] In each of the piezoelectric resonators shown in Figs. 1 to 18, cut portions 24 may be formed by, for example, grinding the base member 12 with sandpaper or the like.

[0052] In the piezoelectric resonator 10 shown in Fig. 18, cut portions 34 may alternatively be formed by, for example, grinding using a barrel. Fig. 19 shows the relationship between the time taken for barreling for forming cut portions 24. As is apparent from the relationship shown in Fig. 19, the resonant frequency Fr of the piezoelectric resonator 10 shown in Fig. 18 is proportional to the barreling time, so that the resonant frequency Fr can be easily adjusted. The antiresonant frequency Fa and other frequencies of the piezoelectric resonator 10 shown in Fig. 19 also change similarly to the resonant frequency Fr, and can therefore be adjusted easily.

[0053] An electronic component such as a vibrator or a discriminator can be manufactured by using each of the above-described piezoelectric resonators 10. Use of the piezoelectric resonator 10 shown in Fig. 7 will be described by way of example. Fig. 20 illustrates an electronic component 60, which includes an insulating material substrate 62 provided as a supporting member. Two pairs of recesses 64 are formed in opposite end portions of the insulating material substrate 62. Pattern electrodes 66 and 68 are formed on one surface of the insulating material substrate 62. One pattern electrode 66 is provided between one opposite pair of the recesses 64 and has a portion extending in an L-shaped form from its one end portion toward a central portion of the insulating material substrate 62. The other pattern electrode 68 is provided between the other opposite pair of recesses 64 and has a portion extending in an L-shaped form from its one end portion toward the central portion of the insulating material substrate 62. These pattern electrodes 66 and 68 are provided so as to extend to the other side of the insulating material substrate 62 via the recesses 64 in a roundabout fashion.

[0054] An electroconductive adhesive or the like (not shown) are applied to end portions of the pattern electrodes 66 and 68 at the center of the insulating material substrate 62. Mount members 70 formed of an electroconductive paste or the like on the external electrodes 20 and 22 of the above-described piezoelectric resonator 10 substantially at the center of the electrodes in the longitudinal direction are mounted on the electroconductive adhesive on the end portions of the pattern electrodes 66 and 68, as shown in Fig. 21.

[0055] Further, a metallic cap 74 is placed on the insulating material substrate 62. To prevent conduction between the metallic cap 74 and the pattern electrodes 66 and 68 when the cap 74 is set, an insulating material such as an insulating resin is applied on the insulating material substrate 62 and the pattern electrodes 66 and 68. Thereafter, the metallic cap 74 is set. In this manner, electronic component 60 is manufactured. In this electronic component 60, the pattern electrodes 66 and 68 formed so as to extend to the other side of the insulating material substrate 62 via the recesses 64 in a roundabout fashion are used as input and output terminals for connection to an external circuit.

[0056] In this electronic component 60, amount members 70 are provided and a central portion of the piezoelectric resonator 10 is fixed on these mount members 70. The ends of the piezoelectric resonator 10 are thereby placed apart from the insulating material sub-

strate 62, so that vibration is not impeded. Also, since the central portion of the piezoelectric resonator corresponding to a nodal point is fixed by the mount members 70, longitudinal vibration excited is not weakened.

[0057] This electronic component 60 is used as, for example, a discriminator by being mounted on a circuit board or the like together with an IC or the like. Since the electronic component 60 of such a structure is enclosed and protected in the metallic cap 74, it can be used as a chip component capable of being mounted by reflow soldering or the like.

[0058] In a case where this electronic component 60 is used as a vibrator, spurious resonance is limited since the above-described piezoelectric resonator 10 is used, thereby preventing abnormal oscillation due to spurious resonance. Also, impedance matching with an external circuit can be easily achieved because the capacitance value of the piezoelectric resonator 10 can be freely set. In particular, in the case of use as a vibrator for a voltage controlled oscillator, a wide variable frequency range unattainable by the conventional art can be obtained because ΔF of the resonator is large.

[0059] In a case where this electronic component 60 is used as a discriminator, the character of the resonator that resides in a large ΔF leads to a characteristically wide separation. Further, since the capacitance design range of the resonator is wide, an impedance matching with an external circuit can be achieved easily. It is also possible to form a ladder type filter by using a plurality of piezoelectric resonators 10. Also in such a case, the degree of design freedom can be improved.

[0060] While the above-described electronic component is provided in a chip form, the electronic component in accordance with the present invention can be provided in any other different form. Needless to say, a structure corresponding to this embodiment including any one of the piezoelectric resonators 10 other than that shown in Fig. 7 may be used.

[0061] In each of the above-described piezoelectric resonators 10, inner electrode 14 is provided over the entire area of the major surface of each piezoelectric layer 12a. According to the present invention, however, inner electrodes 14 may be provided in such a manner that one of the two groups of inner electrodes 14 alternating with each other have no portions provided on upper portions of the major surfaces of the piezoelectric layers 12a on one side, as shown in Fig. 22(a), while the other of the alternate inner electrodes 14 have no portions provided on upper portions of the major surfaces of the piezoelectric layers 12a on the other side, as shown in Fig. 22(b). If electrodes 14 are formed in this manner, the ends of one of the alternate groups of electrodes 14 in one side surface of the base member 12 are not exposed at one end of the base member 12 in the width direction while the ends of the other alternate group of inner electrodes 14 are not exposed at the other end of the base member 12 in the width direction, thereby eliminating the need for insulating films 16 and 18.

[0062] In each of the above-described piezoelectric resonators 10, the plurality of piezoelectric layers 12a are polarized alternately in opposite directions. However, the direction of polarization of the plurality of piezoelectric layers is not limited to this.

[0063] Each of the above-described piezoelectric resonators 10 is formed so that the sizes of the piezoelectric layers 12 in the longitudinal direction of the base member 12 or the spacings between the adjacent electrodes 14 are equal. However, it is not always necessary to set the these sizes or spacings equal to each other.

[0064] In each of the above-described piezoelectric resonators 10, one piezoelectric layer 12a is provided between each adjacent pair of inner electrodes 14. Alternately, a plurality of piezoelectric layers may be formed between each adjacent pair of electrodes 14.

[0065] Further, while in each of the above-described piezoelectric resonators 10 inner electrodes 14 connected to external electrodes 20 and 22 are alternately formed, it is not always necessary to alternately provide inner electrodes 14.

[0066] Also, while in each of the above-described piezoelectric resonators 10 cut portions 24 are formed in two or more places in the base member 12, cut portion 24 may be formed as only one portion in an edge portion or a corner portion of the base member 12. Also in such a case, the invention has the same advantage. Further, cut portions 24 formed in edge and corner portions may be mixedly provided.

[0067] Fig. 23 is a block diagram showing one preferred embodiment of a double-super-heterodyne receiver in accordance with the present invention. The super-heterodyne receiver 200 shown in Fig. 23 includes an antenna 202. The antenna 202 is connected to an input-end of an input-circuit 204. The input-circuit 204 performs an impedance matching between the antenna 202 and a high-frequency amplifier 206 which will be described below. A tuning circuit which elects a desired frequency or a band-pass filter is used as the input-circuit 204. An output-end of the input-circuit 204 is connected to an input-end of a high-frequency amplifier 206. The high-frequency amplifier 206 is used for improving a sensitivity by low-noise amplifying weak radio waves and for improving selectivity of image-frequencies. An output-end of the high-frequency amplifier 206 is connected to an input-end of a first frequency mixer 208. The first frequency mixer 208 is used for making a first integrated or differential intermediate-frequency by mixing a desired frequency and a first local oscillation frequency. The other input-end of the first frequency mixer 208 is connected to an output-end of a first local oscillator 210. The first local oscillator 210 is used for oscillating the first local oscillation frequency to make the first intermediate-frequency. An output-end of the first frequency mixer 208 is connected to an input-end of a first band-pass filter 212. The first band-pass filter 212 is used for passing the first interme-

diate-frequency. An output-end of the first band-pass filter 112 is connected to one input-end of a second frequency mixer 214. The second frequency mixer 214 is used for making a second integrated or differential intermediate-frequency by mixing the first intermediate frequency and a second local oscillation frequency. The other input-end of the second frequency mixer 214 is connected to an output-end of a second local oscillator 216. The second local oscillator 116 is used for oscillating the second local oscillation frequency to make the second intermediate-frequency. An output-end of the second frequency mixer 214 is connected to an input-end of a second band-pass filter 218 The second band-pass filter 218 is used for passing the second intermediate frequency. An output-end of the second band-pass filter 218 is connected to an input-end of an intermediate frequency amplifier 220. The an intermediate frequency amplifier 220 is used for amplifying the second intermediate frequency. An output-end of the intermediate frequency amplifier 220 is connected to an input-end of a detector 222. The detector 222 is used for obtaining signal waves from the second intermediate frequency. An output-end of the second detector 222 is connected to an input-end of a low-frequency amplifier 224. The low-frequency amplifier 224 is used for amplifying the signal waves so that the signal waves can drive a speaker. An output-end of the low-frequency amplifier 224 is connected to a speaker 226.

[0068] In the present invention, the above described piezoelectric resonator can be used as the detector 222 in the double-super-heterodyne receiver 200. And, the above described ladder-filter can be used as each of the first band-pass filter 212 and the second band-pass filter 218.

[0069] As the ladder-filter including the piezoelectric resonator, the ladder-filter disclosed in a Japanese Patent Laid-Open publication No. 51261/1998 for example may be used. In the ladder-filter, four piezoelectric resonators are connected to each other in a ladder fashion. Such receiver is small in size and have a good receiving characteristic.

[0070] In the present invention, the above described piezoelectric resonator can be used as a detector in a single-super-heterodyne receiver. Further, the above described ladder-filter can be used as a band-pass filter. Similar to the above described double-super-heterodyne receiver, such single-super-heterodyne receiver is also small in size and have a good receiving characteristic. While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled man in the art that the forgoing and other changes in form and details may be made therein without departing from the spirit of the invention.

Claims

1. A piezoelectric resonator, comprising:

   a base member having a longitudinal direction and vibrated in the longitudinal vibration;
   a plurality of inner electrodes perpendicular to the longitudinal direction of said base member and arranged along the longitudinal direction of said base member while being spaced apart from each other;
   a pair of external electrodes provided on a surface of said base member and connected to said electrodes;
   said base member including a plurality of piezoelectric material layers laminated to each other;
   said inner electrodes being provided on surfaces of said piezoelectric material layers perpendicular to the longitudinal direction of said base member;
   said piezoelectric material layers being polarized along the longitudinal direction of said base member; and
   said base member having at least one cut portion at its edge portions.

2. The piezoelectric resonator according to Claim 1, wherein; said cut portion is located at corner portions of said base member.

3. A method for adjusting a frequency of a piezoelectric resonator comprising:

   a base member having a longitudinal direction and vibrated in the longitudinal vibration;
   a plurality of inner electrodes perpendicular to the longitudinal direction of said base member and arranged along the longitudinal direction of said base member while being spaced apart from each other; and
   a pair of external electrodes provided on a surface of said base member and connected to said electrodes,
   said base member including a plurality of piezoelectric material layers laminated to each other,
   said inner electrodes being provided on surfaces of said piezoelectric material layers perpendicular to the longitudinal direction of said base member, and
   said piezoelectric material layers being polarized along the longitudinal direction of said base member; comprising the step of:
   removing at least a portion at edge portions of said base member.

4. A method according to Claim 3, wherein;

   said portion removed in the removing step is located at corner portions of said base member.

5. A communication apparatus including a detector, wherein; said detector comprises the piezoelectric resonator of Claim 1 or 2.

6. A communication apparatus including a band-pass filter, wherein; said band-pass filter comprises a ladder-filter including the piezoelectric resonator of Claim 1 or 2.

Fig. 1

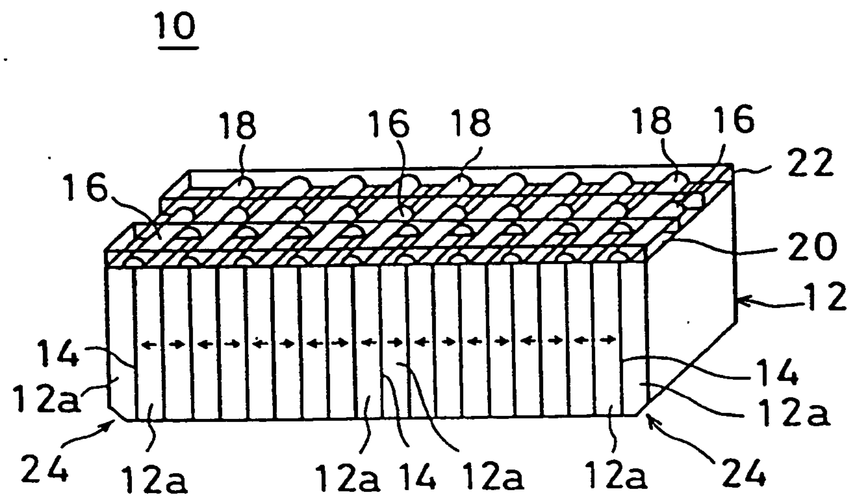
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Fig. 2

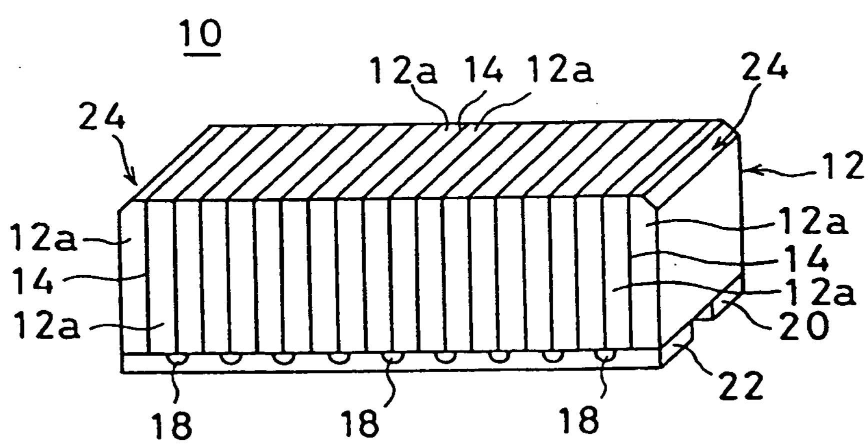
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Fig. 3

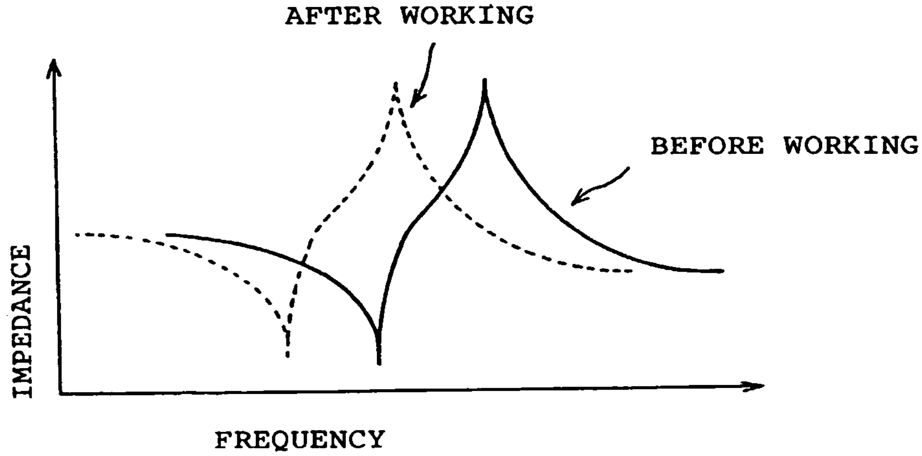
AFTER WORKING
BEFORE WORKING
IMPEDANCE
FREQUENCY

Fig. 4

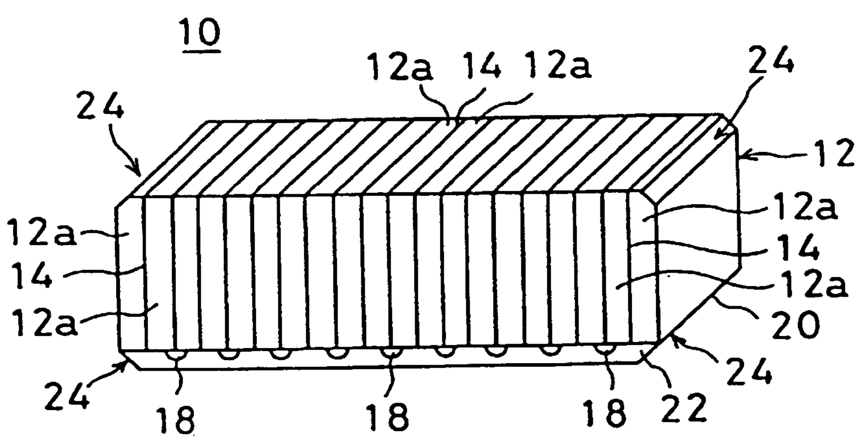
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Fig. 5

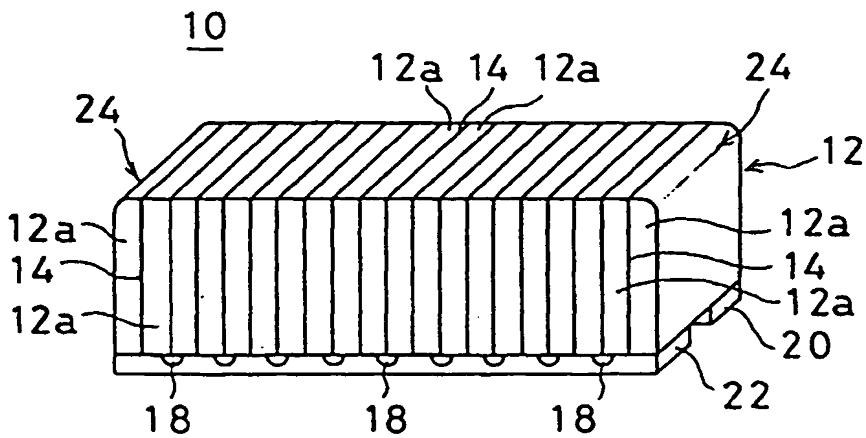
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Fig. 6

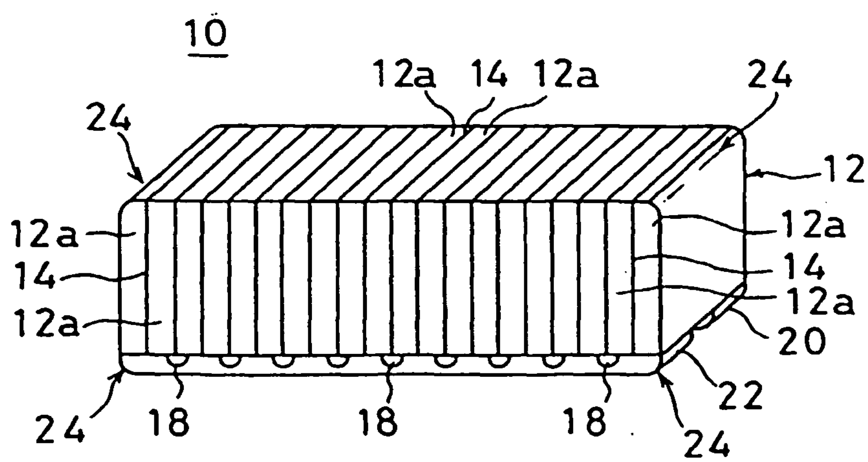
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Fig. 7

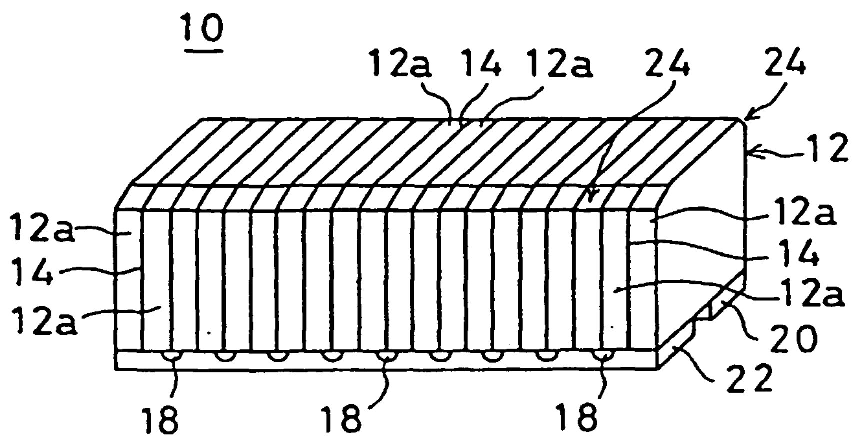
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Fig. 8

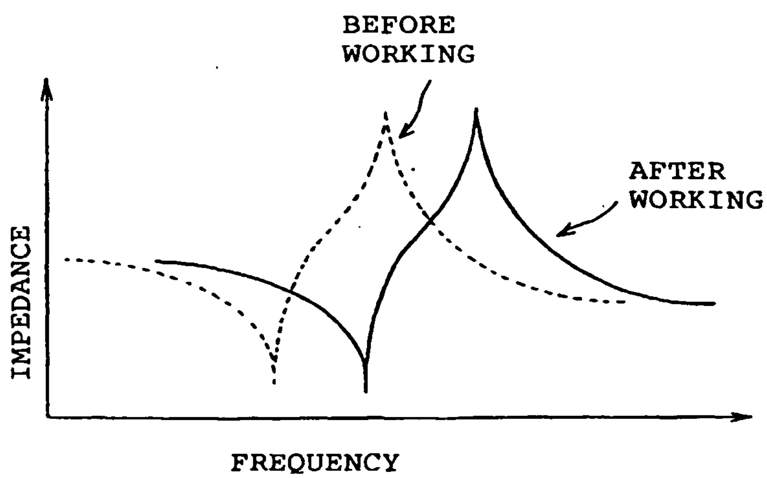
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Fig. 9

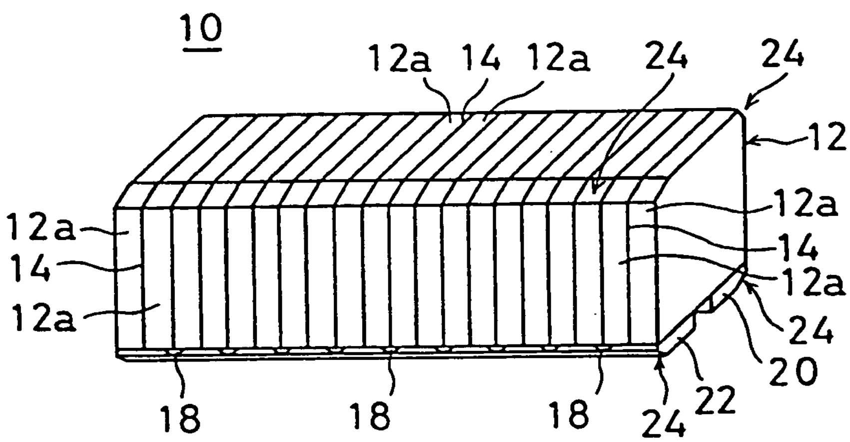
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Fig. 10

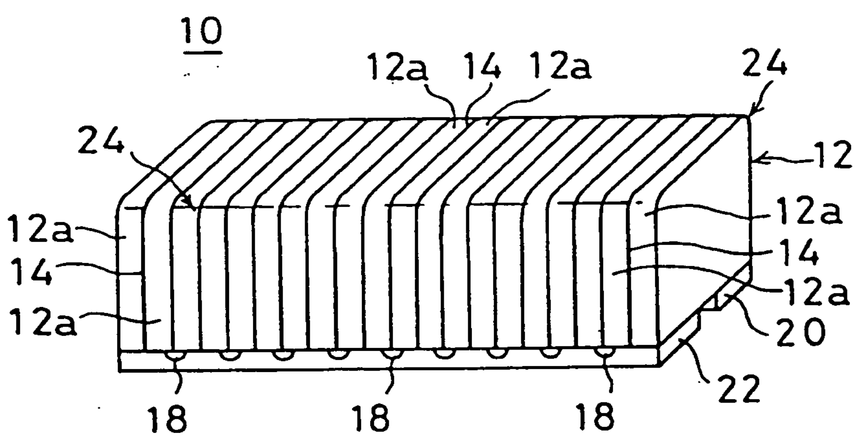
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Fig. 11

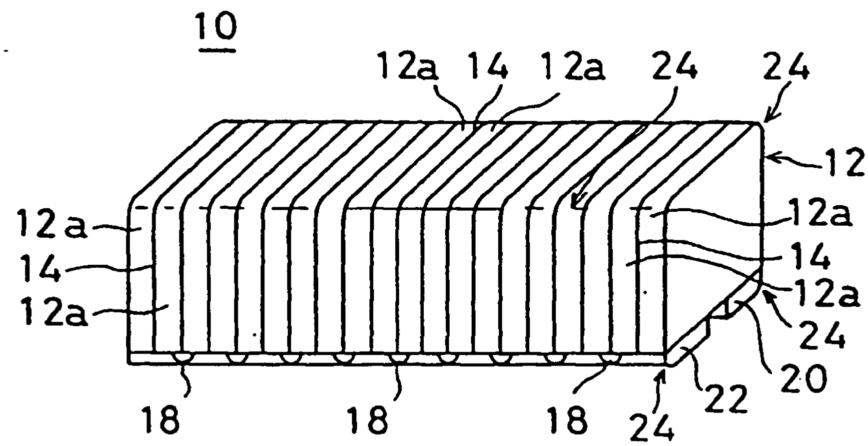
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Fig. 12

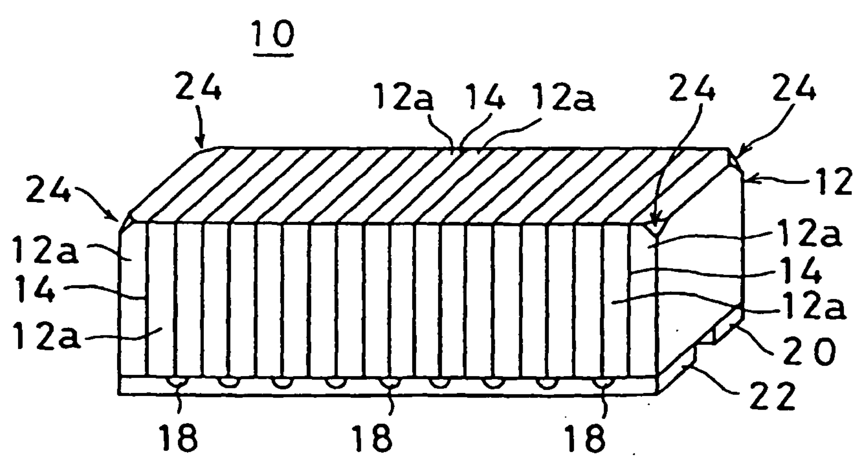
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Fig. 13

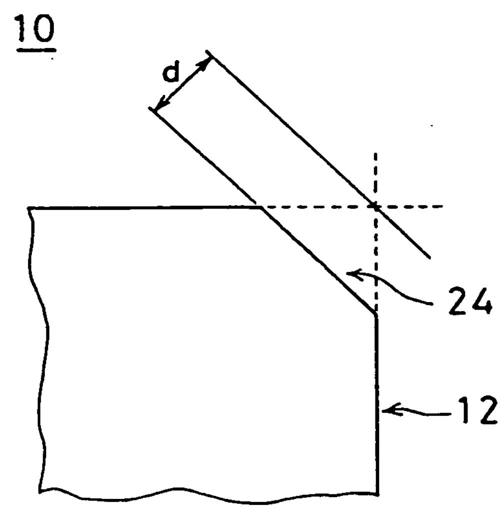
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Fig. 14

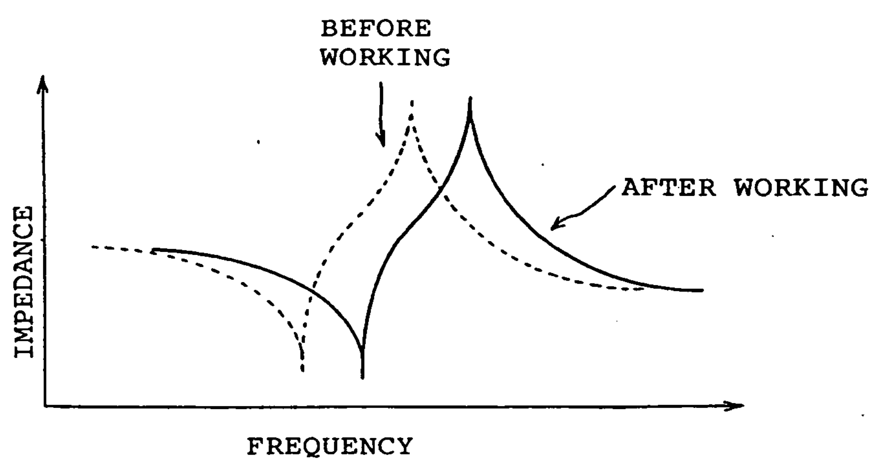
BEFORE WORKING
AFTER WORKING
IMPEDANCE
FREQUENCY

Fig. 15

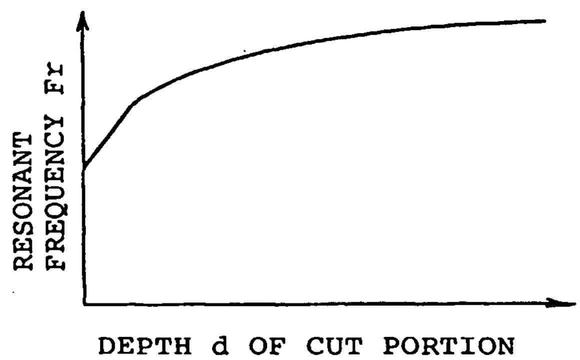
RESONANT
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Fig. 16

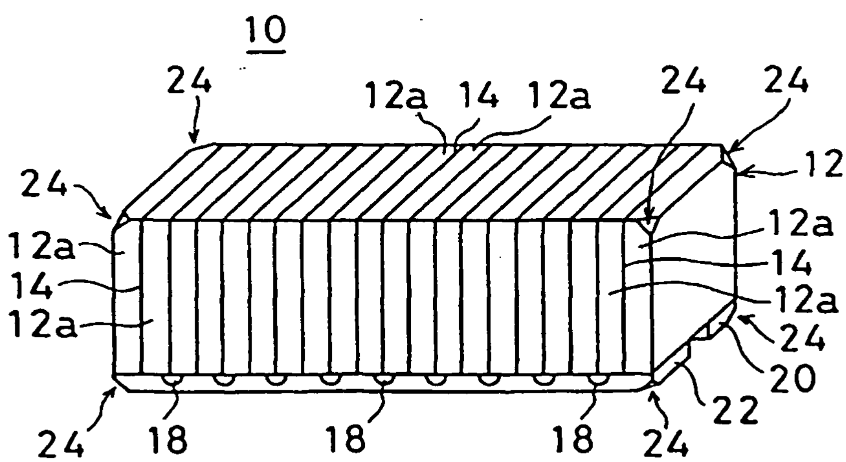
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Fig. 17

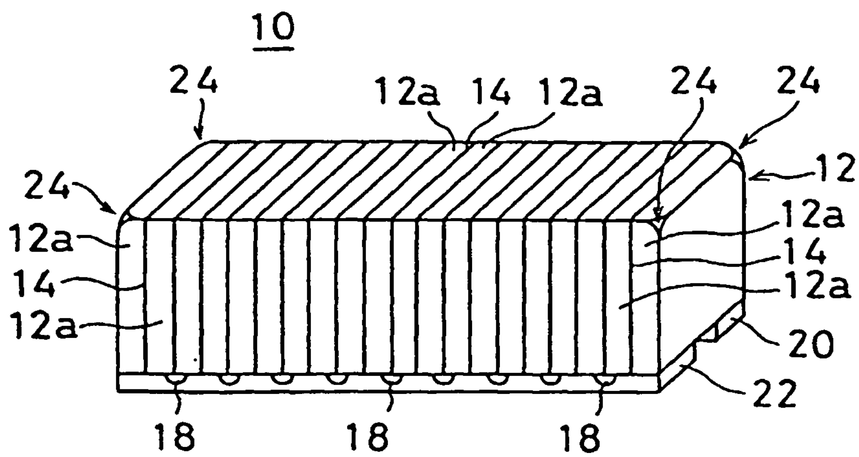
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Fig. 18

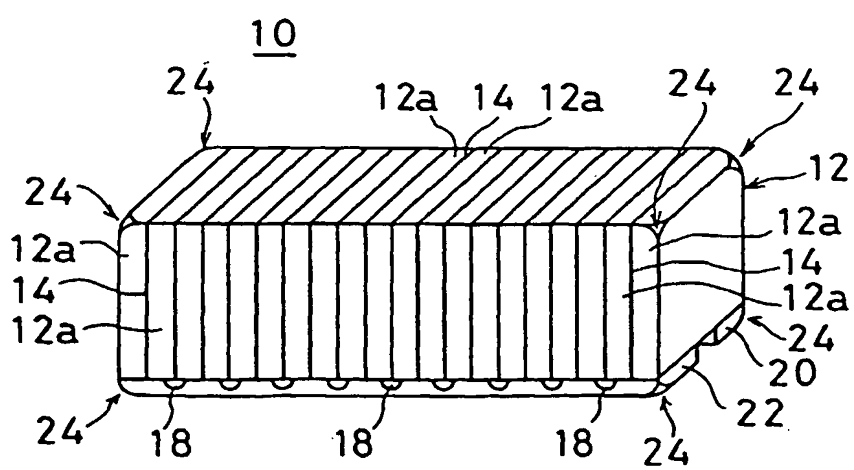
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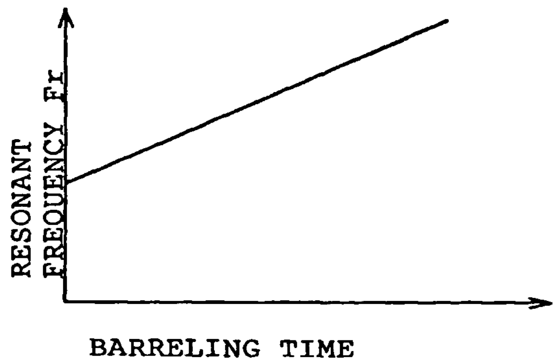
Fig. 19


RESONANT
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BARRELING TIME

Fig. 20

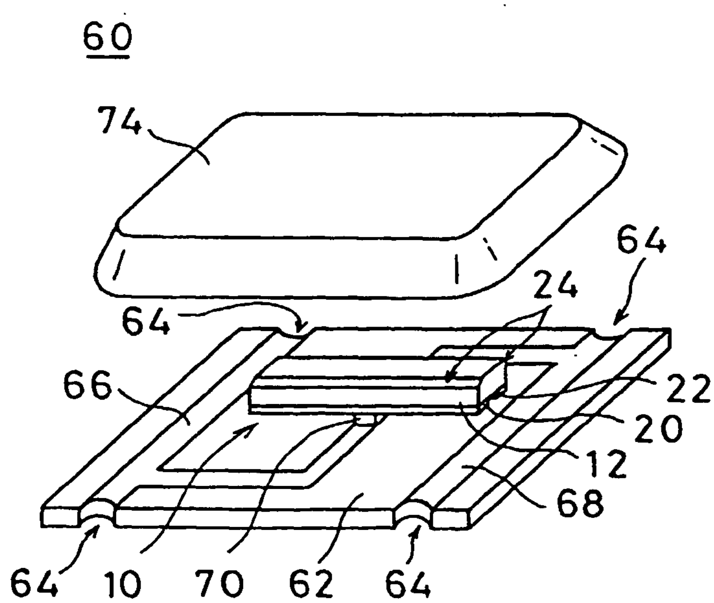
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Fig. 21

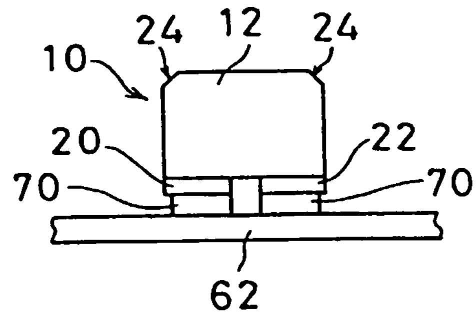

Fig. 22

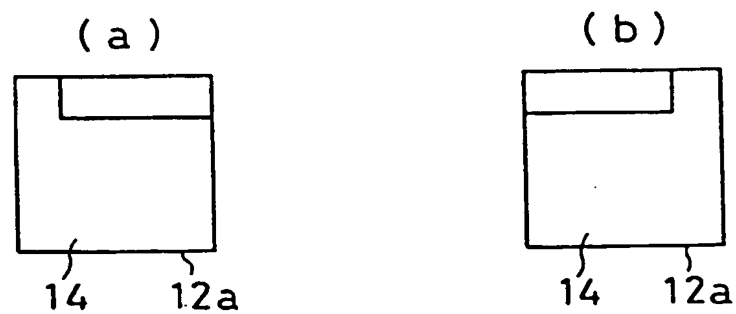

Fig. 24

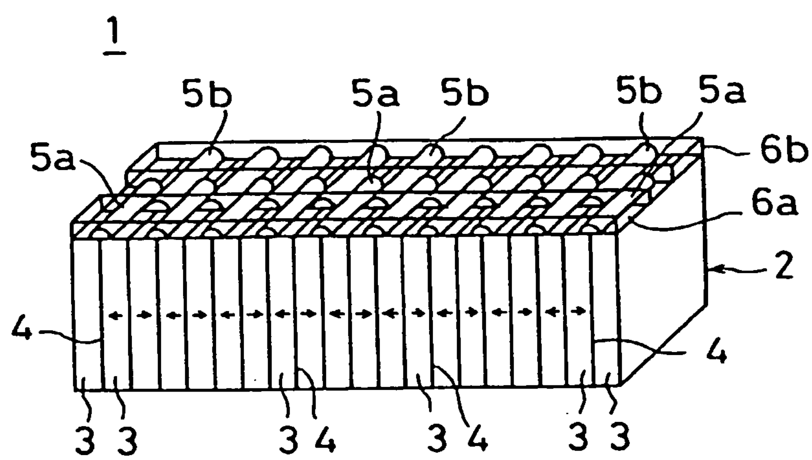

Fig. 23